## VARIATIONS OF G AND SEE PROJECT

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Problems of absolute G measurements, its temporal and range variations ¿from both experimental and theoretical points of view are discussed, and a new universal space project for measuring G, G(r) and G-dot promising an improvement of our knowledge of these quantities by 2-3 orders is advocated.

### 1 Introduction

Among fundamental physical constants Newton's gravitational constant G (as well as other fundamental macroscopic parameters H - the Hubble constant,  $\rho$ , or  $\Omega$ , - mean density of the Universe,  $\Lambda$  - the cosmological constant) is known with the least accuracy. Moreover, there are other problems related to its possible variations with time<sup>11,12</sup> and range<sup>5</sup> coming mainly from predictions of unified models of the four known physical interactions.

Here we dwell upon the problems of absolute G measurements, its temporal and range variations from both experimental and theoretical points of view and advocate a new universal space project for measuring G, G(r) and G-dot promising an improvement of our knowledge of these quantities by 2-3 orders.

Why are we interested in an absolute value of G? It is known in celestial mechanics that we can determine only the product GM, where M is the mass of a body. (GM is known now with the accuracy  $10^{-9}$  which is much better than  $10^{-3}$  for G and correspondingly for masses of planets.) The knowledge of this product is enough for solving most problems in celestial mechanics and space dynamics. But there are other areas where we need separate values of G and G and G in the result of G and G in the result of G in the result of

What is the experimental situation with G?

### 2 Problem of Stability of G

## 2.1 Absolute G measurements

The value of the Newton gravitational constant G as adopted by CODATA in 1986 is based on the Luther and Towler measurements of 1982.

Even at that time other existing on 100ppm level measurements deviated  $\xi$  from this value more than their uncertainties. During recent years the situation, after very precise measurements of G in Germany and New Zealand, became much more vague. Their results deviate from the official CODATA value drastically.

As it is seen from the most recent data announced in November 1998 at the Cavendish conference in London the situation with terrestrail absolute G measurements is not improving. The reported values for G (in units of  $10^{11}$  SI) and their estimated error in ppm are as follows:

Fitzgerald and Armstrong	6.6742	90 ppm
(NZ)	6.6746	134
Nolting et al. (Zurich)	6.6749	210
Meyer et al. (Wupperthal)	6.6735	240
Karagioz et al. (Moscow)	6.6729	75
Richman et al.	6.683	1700
Schwarz et al.	6.6873	1400
CODATA (1986, Luther)	6.67259	128

This means that either the limit of terrestrial accuracies is reached or we have some new physics entering the measurement procedure.<sup>7,8,14</sup> The first means that we should address to space experiments to measure  $G^9$  and the second means that a more thorough study of theories generalizing Einstein's general relativity is necessary.

# 2.2 Data on temporal variations of G

Dirac's prediction based on his Large Numbers Hypothesis is  $\dot{G}/G = (-5)10^{-11}~year^{-1}$ . Other hypotheses and theories, in particular some scalar-tensor or multidimensional ones, predict these variations on the level of  $10^{-12} - 10^{-13}$  per year. As to experimental or observational data, the results are rather inconclusive. The most reliable ones are based on Mars orbiters and landers (Hellings, 1983) and on lunar laser ranging (Muller et al., 1993; Williams et al., 1996). They are not better than  $10^{-12}$  per year.<sup>7,14</sup> Here are some data on  $\dot{G}$ :

1. Van Flandern, 1976-1981:	$\dot{G}/G = -5 \cdot 10^{-11} y^{-1}$
(ancient eclipses)	
2. Hellings, 1983-1987:	$ \dot{G}/G  < 5 \cdot 10^{-12} y^{-1}$
(Viking)	
3. Reasenberg, 1987:	$ \dot{G}/G  < 5 \cdot 10^{-11} y^{-1}$
(Viking)	
4. Acceta et al., 1992:	$ \dot{G}/G  < 10^{-12} y^{-1}$
(Nucleosyntheses)	
5. Anderson et al., 1992:	$ \dot{G}/G  \le 2 \cdot 10^{-12} y^{-1}$
(ranging to Mercury and Venus)	
6. Muller et al., 1993:	$ \dot{G}/G  \le 5 \cdot 10^{-13} y^{-1}$
(lunar laser ranging)	
7. Kaspi et al., 1994:	$ \dot{G}/G  \le 5 \cdot 10^{-12} y^{-1}$
(timing of pulsars)	
8. Williams et al., 1996:	$ \dot{G}/G  \le 8 \cdot 10^{-12} y^{-1}$
(lunar laser ranging)	

Here once more we see that there is a need for corresponding theoretical and experimental studies. Probably, future space missions to other planets will be a decisive step in solving the problem of temporal variations of G and determining the fate of different theories which predict them as the larger is the time interval between successive measurements and, of course, the more precise they are, the more stringent results will be obtained.

# 2.3 Nonnewtonian interactions (EP and ISL tests)

Nearly all modified theories of gravity and unified theories predict also some deviations from the Newton law (ISL) or composite-dependent violation of the Equivalence Principle (EP) due to appearance of new possible massive particles (partners).<sup>5</sup>

In the Einstein theory G = const. If G = G(t) is possible, then, from the relativistic point of view  $G \to G(t,r)$ . In more detail: Einstein's theory corresponds to massless gravitons which are mediators of the gravitational interaction, obey 2nd order differential equations and interact with matter with a constant strength G.

Any violation of these conditions leads to deviations from the Newton Law. Here are some classes of theories (generalized gravitational and inified models) which exibit such deviations.

- 1. Massive gravitons: theories with  $\Lambda$  and bimetric.
- 2. Effective G(x,t): scalar-tensor theories.
- 3. Theories with torsion.
- 4. Theories with higher derivatives (4th order etc.). Here massive modes appear: short and long range forces.
- 5. Other mediators besides gravitons (partners) appear: SuperGravity, SuperStrings, M-theory etc. (massive).
- 6. Theories with nonlinearities induced by any of the known interactions (electromagnetic or gravitational or other). Then, some mass of the mediators appears.
- 7. Phenomenological models where the mechanism of deviation from the Newton law is not known (fifth force or so). For describing the possible deviation ¿from the Newton law the usual parametrization  $\Delta \sim \alpha e^{-r/\lambda}$  of the Yukawa-type is used.

Experimental data exclude the existence of these particles at nearly all ranges except less than a millimeter and also at meters and hundreds of meters ranges. Here are some estimations of masses, ranges and also strengths for G(r) predicted by various models.

- 1. Pseudoscalar particle leads to attraction between macro bodies with range  $2 \cdot 10^{-4} \, \mathrm{cm} < \lambda < 20 \, \mathrm{cm}$  (Moody, Wilizek, 1984), the variable  $\alpha$  (strength) from 1 to  $10^{-10}$  in this range is predicted.
- 2. Supersymmetry: spin-1 partner of the massive spin-3/2 gravitino leads to repulsion in the range:  $\lambda \sim 10^3$  km,  $\alpha \sim 10^{-13}$  (Fayet, 1986, 1990).
- 3. Scalar field to adjust  $\Lambda$  (Weinberg, 1989):  $m \leq 10^{-3} \, eV/c^2$  or range  $\lambda \geq 0.1$  mm. Another variant (Peccei, Sola, Wetterich, 1987) leads to  $\lambda \leq 10$  km (attraction).
- 4. Supergravity (Scherk, 1979); graviton is accompanied by a spin-1 graviphoton: here a repulsion is predicted also.
- 5. Strings, p-branes, M-theory: dilaton (other scalar fields) and antisymmetric tensor fields appear.

**Conclusion:** there is no reliable theory or model of unified type, but all predict new interactions of a non-Newtonian character (composition dependent *EP*-violation or independent).

It is a real challange to experimental people!

It should be noted that the most recent result in the range of 20-500 m was obtained by Achilli et al.<sup>10</sup> They found a deviation from the Newton law with the Yukawa potential strength  $\alpha$  between 0,13 and 0,25. Of course, these results need to be verified in other independent experiments, probably in space ones.

## 3 SEE Project

We saw that there are three problems connected with G: absolute value mesurements and possible variations with time and range. There is a promissing new space experiment SEE - Satellite Energy Exchange<sup>9</sup> which addresses to all these problems and may be more effective in solving them than other laboratory or space experiments.

We studied some aspects of the SEE-Project.<sup>15</sup>

- 1. Wide range of trajectories with the aim of finding optimal ones:
- circular in spherical field;
- circular in spherical field + earth quadrupole modes;
- elliptic, with e < 0.05.
- 2. Estimations of other celistical bodies influence.
- 3. Estimations of relative influence of trajectories to  $\delta G$ ,  $\delta \alpha$ .
- 4. Modelling measurement procedure of G and  $\alpha$ .
- 5. Estimations of some sources of errors:
- radial oscilations of the shepherd's surface;
- longitudal oscilations of the capsule;
- transversal oscilations of the capsule;
- shepherd nonsphesicity;
- limits on shepherd  $J_2$ .
- 6. Error budgets for G, G-dot and G(r). The general conclusion is that the Project SEE may improve our knowledge of G, limits on G-dot and G(r) by 2-3 orders of magnitude.
  - 7. Variation of the SEE method trajectories near libration points.
- 8. Different altitudes up to ISS (500 km), short capsule up to 5 m (instead of original 15-20 m).

**General conclusion:** it is possible to improve  $(G, \alpha)$  by 2-3 orders at a range of 1-100 m.

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#### References

- [1] V.N. Melnikov, Multidimensional Classical and Quantum Cosmology and Gravitation. Exact Solutions and Variations of Constants. CBPF-NF-051/93, Rio de Janeiro, 1993;
  - V.N. Melnikov. In: Cosmology and Gravitation, ed. M.Novello (Editions Frontieres, Singapore, 1994) p. 147.
- [2] V.N. Melnikov, Multidimensional Cosmology and Gravitation, CBPF-MO-002/95, Rio de Janeiro, 1995, 210 p.
  - V.N. Melnikov. In *Cosmology and Gravitation.II* ed. M. Novello (Editions Frontieres, Singapore, 1996) p. 465.
- [3] K.P. Staniukovich and V.N. Melnikov, *Hydrodynamics*, *Fields and Constants in the Theory of Gravitation*, (Energoatomizdat, Moscow, 1983), (in Russian).
- [4] V.N. Melnikov, Int. J. Theor. Phys. 33, N7, 1569 (1994).
- [5] V. de Sabbata, V.N.Melnikov and P.I.Pronin, Prog. Theor. Phys. 88, 623 (1992).
- [6] V.N. Melnikov. In: Gravitational Measurements, Fundamental Metrology and Constants. Eds. V. de Sabbata and V.N. Melnikov (Kluwer Academic Publ.) Dordtrecht, 1988, p.283.
- [7] A.J. Sanders and G.T. Gillies, Rivista Nuovo Cim. 19, N2, 1 (1996).

- [8] A.J. Sanders and G.T. Gillies, Grav. and Cosm. 3, N4(12), 285 (1997).
- [9] A.J. Sanders and W.E. Deeds. Phys. Rev. **D** 46, 480 (1992).
- [10] V. Achilli et al., Nuovo Cim. B 12, 775 (1997).
- [11] Y.-S. Wu and Z. Wang, Phys. Rev. Lett. 57 1978 (1986).
- [12] K.A. Bronnikov, V.D. Ivashchuk and V.N. Melnikov, Nuovo Cimento B 102, 209 (1988).
- [13] T. Damour, "Gravitation, Experiment and Cosmology", gr-qc/9606079.
- [14] V.D. Ivashchuk and V.N. Melnikov, "Multidimensional Cosmological and Spherically Symmetric Solutions with Intersecting p-Branes". In Proc. 2nd Samos Meeting on Cosmology, Geometry and Relativity, September 1998, Springer; gr-qc/9901001.
- [15] A.D. Alexeev, K.A. Bronnikov, N.I. Kolosnitsyn, M.Yu. Konstantinov, V.N. Melnikov and A.G. Radynov, *Izmeritel'naya Tekhnika*, 1993, No. 8, p.6; No. 9, p.3; No. 10, p.6; 1994, No. 1, p.3;
  - Int. J. Mod. Phys. **D** 3, No. 4, p.773 (1994).